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# **Mechanical Property of Roof Plate Based on Engineered Cementitious Composites**

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Abstract. In order to replace the steel roof in the Tibet of China, the roof plate based on engineered cementitious composites was studied. The results show that roof plate based on engineered cementitious composites is suitable for large deformation of structures. In order to reduce the weight of the roof plate, ribs are more suitable for upward.

#### **1. Introduction**

In Tibet of China, the climate is harsh and the temperature difference between day and night is large. In the aspect of building roof, if steel structure is chosen, the surface treatment is easy to wrinkle. Considering the multiple earthquakes in Tibetan area, engineered cementitious composites (ECC) is selected here to replace the steel roof. ECC, invented by Victor Li of the University of Michigan in the United States, have been designed and adjusted to produce high toughness cement-based composites based on the principles of fracture mechanics and micro-mechanics [1]. The ultimate tensile strain of the material can reach more than 2%, and the relationship between tensile stress and strain does not decrease with the increase of strain, which is commonly called strain hardening phenomenon. The formation of multiple micro-cracks during tension increases the macro-tensile strain by 100 to 300 times and the fracture energy by nearly 1000 times, which makes the cement-based materials change from traditional brittle materials to ductile materials similar to metals. In addition, ECC has a certain self-healing ability making it has waterproof ability [2]. Due to its excellent stress-strain properties, the application of this material in future civil engineering has attracted wide attention of scholars at home and abroad, and is considered as one of the main ways to improve the toughness of cement-based structural materials. The material has been successfully applied to repair the large-scale aging and cracking of Hiroshima Sanying Dam in Japan. At the same time, Japan, the United States, Europe and Korea have been widely used in many practical projects, including tunnel, railway, bridge, high-rise building, station reconstruction and reinforcement. Xu Shifeng's team also has applied this material to the construction of high roller compacted concrete cofferdam and conducted demonstration study on its application [3, 4]. Laboratory and field studies also show that ECC has excellent adhesion, impermeability and seismic performance [5-7].

In this paper, the effect of fiber content on the mechanical properties and bending properties of ECC was studied, and the bending properties of ECC under uniform load were studied by preparing 1:1 roof plate. Finally, the force distribution of ECC roof slab was simulated by FLAC.

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### 2. Materials and Methods

#### 2.1. Materials

P.O 42.5R cement and class I fly ash were used as binder. Quartz powder with particle size of 200 meshes was used as aggregate. Polyvinyl alcohol fiber (PVA) was used to increase the toughness. The density of PVA is 1300 kg/m<sup>3</sup>, the ultimate tensile strength is 1540 MPa, the elastic modulus is 37.2 GPa, the diameter is 40  $\mu$ m, the length of PVA is 12 mm. The dosages of PVA are 0%, 1%, 1.5% and 2% by volume. The self-developed polycarboxylate superplasticizer and deformer were used to adjust the working performance of ECC. The mix design of ECC is listed in Table 1. In this study, the mix with PVA content of 19.5 kg/m<sup>3</sup> was used to prepare the 1:1 roof plate.

No.	PVA	Cement	Fly ash	Quartz powder	Water	Deformer	Superplasticizer
1	0	550	660	498.2	302.5	0.182	26
2	13	550	660	498.2	302.5	0.182	26
3	19.5	550	660	498.2	302.5	0.182	26
4	26	550	660	498.2	302.5	0.182	26

Table	1.	Mix	design	of ECC
Lanc		11117	ucongin	of LCC

#### 2.2. Sample Preparation and Testing

Cement and fly ash were mixed in a forced mixer for 30 seconds, then water with superplasticizer and defoamer were added in the mixer stirring for 6 minutes, then PVA fiber was added and stirred for 3 minutes. Samples with sizes of  $40 \times 40 \times 160$  mm and  $400 \times 100 \times 10$  mm were prepared on a vibration table. After curing at 20 °C and relative humidity of >90% environment, the samples were used for the mechanical and bending testing. The size of actual proportional roof plate is  $2 \times 1$  m. The specific shape is shown in Fig.1.

The compressive strength and flexural strength were tested on a hydraulic mortar machine. The four point bending was used for the bending property testing (Fig.2). The load is applied by weight to simulate the load distribution of the actual roof plate. The actual test scenario is shown in Fig.3. During the test, the mid-span deflection was recorded by micrometer. Finally, FLAC is used to simulate the stress and displacement of roof plate. Modulus of elasticity of ECC is selected as 15 GPa and Poisson's ratio is 0.27.

#### **3. Results and Discussion**

#### 3.1. Mechanical Properties



Figure 1. Size of actual roof plate



Figure 2. Four points bending testing

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Figure 3. Load distribution of actual roof plate

The compressive strength and flexural strength of ECC at 14 day are listed in the Table 2. It can be seen from Table 2 that with the increase of PVA content the flexural strength increases significantly, but the compressive strength has a little effect. Therefore, the compressive-flexural ratio increases with the fiber increase, illustrating the toughness increase of ECC. In general, the compression flexural ratio of normal concrete is about 10. However, the ratio of ECC is much lower than normal concrete. This shows that the ECC has excellent crack resistance.

No.	Flexural strength	Compressive strength	Compression-Flexural ratio	
	(MPa)	(MPa)		
1	9.2	50.2	5.46	
2	12.1	51.2	3.49	
3	20.2	52.9	2.62	
4	21.5	52.2	2.43	

Table 2. Mechanical properties of ECC

#### 3.2. Four Points Bending Test

The results of four points bending test are listed in Table 3. It can be seen from tabe 3 that the ultimate failure load increases with the increase of fiber content. This is similar with the test of flexural strength. The mid-span deflection in failure increases significantly when the fiber content increases from 1% to 1.5%. The failure form also transfers from brittle fracure to high ductile failure. And when the fiber content lower than 1%, only one main crack was found when the penal failure. When the fiber content increases from 1.5% to 2%, the panals present multi-slit cracking effect and the crack spaceing decreases from 5 mm to 2.9 mm. The multi-slit cracing effect and fracture morphology of ECC with 1.5% PVA are shown in Figs.4 and 5. From Fig.5 it can be seen that Fiber pull-out failure happens during the failure process.

Table 3. The results of four points bending test

No.	Ultimate failure	mid-span deflection	Failure form	Crack spacing
	load (N)	in failure (mm)		(mm)
1	230	2	Brittle fracture	A main crack
2	271	5	Brittle fracture	A main crack
3	364	34	High ductile	5
4	415	40	High ductile	2.9

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**Figure 4.** Multi-slit cracking effect diagram of ECC containing PVA of 1.5%



Figure 5. Fracture morphology of ECC containing PVA of 1.5%

#### 3.3. Actural Roof Plate Bending Property

The load-deflection curves of the actural roof plate are shown in Figs.6 and 7. From Figs.6 and 7 it can be seen that the roof plate also present strain hardening during loading. When the plate ribs downloard, the initial crack load is about 250 kg, but when the ribs upward, the initial crack load is increased to about 550 kg. The cracks of plate with ribs downward and upward are shown in Figs.8 and 9. When the ribs downward, the main crack present at the ribs, but when the ribs upward, uniform cracks appear on the surface of the plate, and no main cracks occur.



Figure 6. Plate ribs downward

Figure 7. Plate ribs upward



Figure 8. Cracks of plate when the ribs downward

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Figure 9. Cracks of plate when the ribs upward

## 3.4. Numerical Simulation of ECC Roof Plate

The maximum principal stress of roof plate with simply supported ends boundary on the two short sides are shown in Figs.10 and 11. When the  $\sigma$ =12500 Pa was applied on the surface of roof plate with ribs downward, the maximum principal tensile stress occurs in the longitudinal rib near the midpoint. This is demonstrated by the Fig.8. When the  $\sigma$ =27500 Pa was applied on the surface of roof plate with ribs upward, the maximum principal compressive stress occurs in the longitudinal rib near the midpoint. Although the ECC has excellent tensile property, it is more resistant to pressure. Therefore, the mechanical property of roof plate with ribs upward is better.



Figure 10. Maximum principal stress nephogram when the ribs downward



Figure 11. Maximum principal stress nephogram when the ribs upward

## 4. Conclusions

The compressive strength, flexural strength and bending property of ECC and the bending property of ECC roof plate were investigated. The stress of roof slab is also simulated numerically. The results show that ECC can be used for roof plate according to the results of compressive strength and flexural strength. It is suitable for large deformation of structures in earthquake area. In order to reduce the weight of the roof plate, ribs are more suitable for upward.

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